DoD SPECTRUM MANAGEMENT: A CRITICAL ANALYSIS

GRADUATE RESEARCH PAPER

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Abstract

Department of Defense spectrum management is a crucial element of our national defense. Within spectrum management we will either exercise proper controls or we will hamper our own ability to achieve victory. The spectrum management process does not belong to the Department of Defense (DoD), and we must work with other government agencies. Time tables are often short, especially during wartime operations, and this is all the more reason why spectrum management processes should be followed. This research includes an analysis of current National, DoD, Joint, and Air Force publications and instructions, as well as a review of Government Audit Agency studies to see where DoD is today regarding spectrum management. Recommendations are provided for improving visibility into spectrum management and to improve the overall process.

Acknowledgements

I would like to express my sincere appreciation to all those that helped make my year at AFIT a successful and memorable experience. I cannot thank my graduate research paper advisor, Dr. Robert Mills, enough for his countless hours of guidance, thought-provoking questions, and constant vectoring throughout my writing of this paper.

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William J. Morgan

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DoD SPECTRUM MANAGEMENT: A CRITICAL ANALYSIS

I. Introduction

Background

In 1967 while attached to the Chief of Naval Operations, Vice Admiral. Jon E. Boyes stated:

> *Radio frequency (RF) management is done by experts who meld years of experience with a curious blend of regulations, electronics politics and not a bit of larceny. They justify requirements, horse trade, coerce, bluff and gamble with an intuition that cannot be taught other than by long experience.*

It is unfortunate that forty years later this statement is only true of a small segment of the career field. The office of the Assistant Secretary of Defense (OASD) and United States Strategic Command (USSTRATCOM) J-8 performed a Network & Spectrum Management Functional Solutions Analysis and presented the outcome of this analysis on 28 Apr 08. This report stated that: "There is limited assured access to and management of the electromagnetic spectrum" (Schoenborn, 2008).

They spelled out the need for many near-, mid- and long-term actions which will require an overhaul of training, software tools, regulatory strategies, and doctrine. They specified that many of these requirements, with the proper funding, could be achieved by 2011.

Motivation

Spectrum management is a cyberspace discipline whose processes exist under the control of many federal government agencies and is limited by international treaties and status of forces agreements. Changes are very slow in happening in both of these arenas. Cyberspace specialists will have to work within these limitations and challenges for many years to come unless flag officers become involved and refuse to allow this mentality of "this is the way it has always been done" to be an acceptable answer for the lack of improvement.

Purpose

The purpose of this paper is to provide a basic understanding of spectrum management, provide details of some of the challenges, and recommendations on where to find the answers. It is hoped that this paper will inspire change from our leaders.

Scope

This paper discusses the main elements of spectrum management from a non-technical perspective. It will provide a good definition of each element, and identify the problems that the Department of Defense (DoD) spectrum management, and user community is having as a result of these problem areas. It will also delve into areas of spectrum management doctrine (Joint Publications), organization (Federal, DoD level, and Air Force), training (Federal and Air Force), and selection of top spectrum management materiel (National Telecommunications and Information Administration and Joint Spectrum Center provided software and databases only).

The paper will also make recommendations on how the spectrum management elements, doctrine, organization, training, and materiel can be improved in the future to meet DoD mission needs.

Assumptions

It is assumed that the Joint Publications and other doctrinal publications citcited in this paper are current and describe existing DoD spectrum management doctrine. It is also assumed that the definitions of spectrum management elements are clear and sufficient to understand the nature of the element and the problems in each area.

Outline

This remainder of this report is outlined as follows. Chapter 2 discusses the current state of spectrum management with careful scrutiny on the elements, doctrine, organization, training and materiel. Chapter 3 provides recommendations for improving the DoD's spectrum management process in the areas of the elements, doctrine, organization, training and materiel. Chapter 4 provides a summary and recommendations for future research.

II. DoD Spectrum Management – Today

Spectrum Elements

Before we can look into the essential elements of spectrum management, it is critical to understand what the spectrum is. The spectrum that is managed is the electromagnetic or radio spectrum. A good definition is given below:

> *The range of electromagnetic radiation (electromagnetic waves) in our known universe, which includes visible light. The radio spectrum, which includes both licensed and unlicensed frequencies up to 300GHz has been defined worldwide in three regions: Europe and Northern Asia (Region 1); North and South America (Region 2), and Southern Asia and Australia (Region 3). Some frequency bands are used for the same purpose in all three regions while others differ.* (Werbach, 2008).

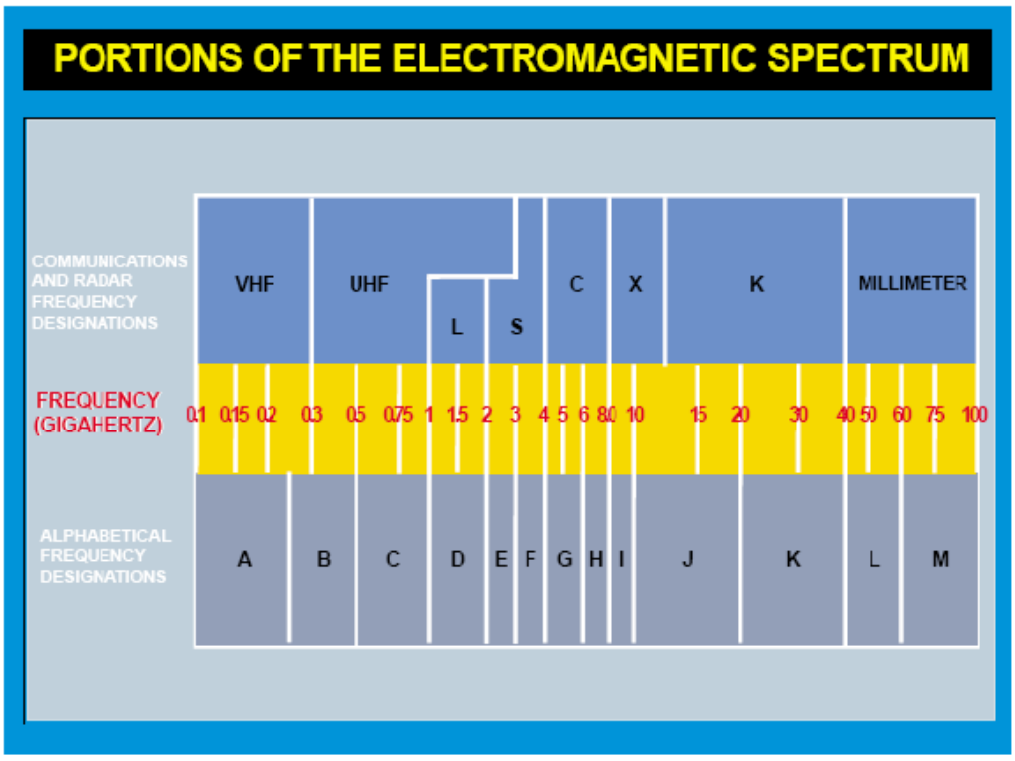

Figure 1 Electromagnetic Spectrum (Portigal, 2004)

Spectrum Management is defined by Joint Pub 3-13.1 as the

> *Planning, coordinating, and managing joint use of the electromagnetic spectrum through operational, engineering, and administrative procedures. The objective of spectrum management is to enable electronic systems to perform their functions in the intended environment without causing or suffering unacceptable interference.* (Joint Publication 3-13.1, 2007).

For the DoD we have both battlefield and non-battlefield spectrum management. The battlefield composes a lot of the same elements as the non-battlefield with the exception of the Joint Resource Frequency Listing (JRFL) which we discuss in further detail later in this chapter. The terminology is very broad, and a list of common terms is included in Appendix A.

Spectrum Allocation and Allotments

All discussions of DoD Spectrum Management elements should start with frequency allocation and allotments. The electromagnetic spectrum is divided into frequency bands with are called spectrum allocations. These allocations specify what radio services (e.g., fixed, mobile, satellite, etc.) are allowed to operate in those bands. A complete list of radio services is found in Appendix B. Figure 2 United States Frequency Allocations (NTIA, 2008) shows the United States (U.S.) frequency allocations, with different colors representing the various services. The entire spectrum allocation is difficult to read in one figure, and it is included here only to demonstrate the scope and complexity of the U.S. spectrum allocations.

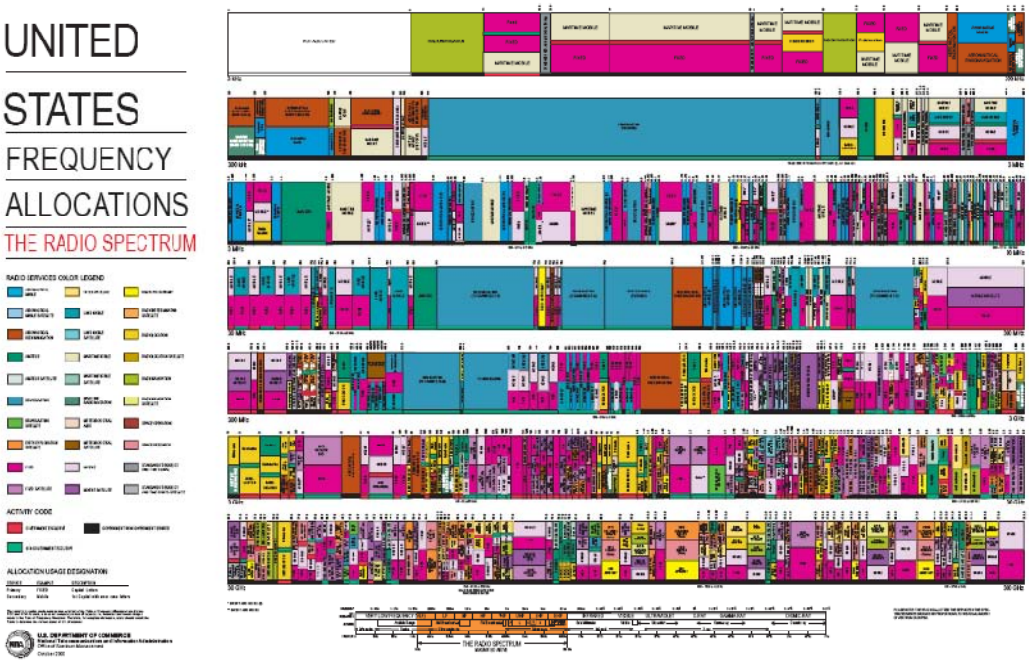

Figure 2 United States Frequency Allocations (NTIA, 2008)

These frequency allocations are further broken out into frequency channel allotments or bands. These bands are managed in the U.S. by the National Telecommunications and Information Administration (NTIA) Interdepartmental Radio Advisory Committee (IRAC). Each nation manages its own spectrum bands in a similar manner since the RF spectrum is one of its most important resources. For example, many nations (including the U.S.) have sold portions of the frequency spectrum to raise funds. The frequency allotments are managed to prevent television and radio stations and other users of the spectrum from interfering with each other. Many radio services for the federal, DoD, and military services use allotment plans for many of their radio services.

This system of allocation and allotment works well enough for most civilian applications. The problem comes with the latest interpretation of the

allotment plans by the military departments. The military Land Mobile Radios (LMRs) are an important communications method used by commanders, administrative professionals, logistics and maintenance personnel, and security forces; therefore, there was an allotment plan generated for these LMRs. The military departments have different requirements depending on the operating locations in the continental U.S. (excluding Hawaii and Alaska).

Historically, there were easy arrangements between the services on exceptions to the national allotment plan. The installation (base/fort) spectrum manager would forward a request for an exception through Command channels to their department's Frequency Management Office (FMO), who would in-turn coordinate with the specified owner of the desired frequency allotment. Typically, the request could be handled easily within a day.

The current FMOs have changed this procedure to requiring a detailed request which is handled by committee, and the response may take months. An example of this was a need by the DoD operating in New Mexico for another LMR channel. The best channel was one allocated to the Navy for shipboard communications. The Navy does not conduct many operations in New Mexico, so it appears that approving the use of the spectrum would be trivial. Instead, this new procedure took three months to get approved which caused mission delays to a test group operating in Albuquerque. Simple requirements should not be made harder when they don't satisfy a real need. The DoD does not have enough manpower to create extra work.

Spectrum Certification

AFI 33-118, Electromagnetic Spectrum Management, defines spectrum certification as

> *The process of reviewing the equipment characteristics to determine realistic supportability expectations to include conformance with the international and national allocation tables, and Electromagnetic Compatibility (EMC) standards.* (AFI 33-118, 2005).

Certification applies to the particular piece of equipment or system which is evaluated and/or approved. Once a system has been approved it can be used on any platform, even between different military services. Spectrum certification data is the foundation of the house upon which our equipment is able to operate. If the foundation is weak, then the house will not stand for long. That is one of the weaknesses of the system. Much of the data is out of date and often inaccurate. Spectrum certification is not taught in any of our training schools and less than ten percent of our spectrum managers can properly complete the spectrum certification application – currently the DD Form 1494.

Another problem is that the DoD depends entirely on manufacturers to provide the data needed for certification. There have been many times when the manufacturer is challenged on the data. Usually, the manufacturer has had to re-file the application due to incompleteness or inaccuracies; sometimes we do not find the problems until we are operating the equipment. When this happens it takes an extensive amount of time to correct the data. This is not due to willful negligence on the part of the manufacturer. Rather, it is often due to lack of understanding on their part for what is required. Unlike frequency assignments,

there is no common manual within the DoD to complete a spectrum certification application.

Figure 3 shows the Air Force flowchart of the certification process. The key organizations involved are: Air Force Frequency Management Agency (AFFMA), Military Communications Electronics Board (MCEB), National Telecommunications and Information Administration (NTIA), Spectrum Planning Subcommittee (SPS), Joint Spectrum Center (JSC), and Major Command (MAJCOM).

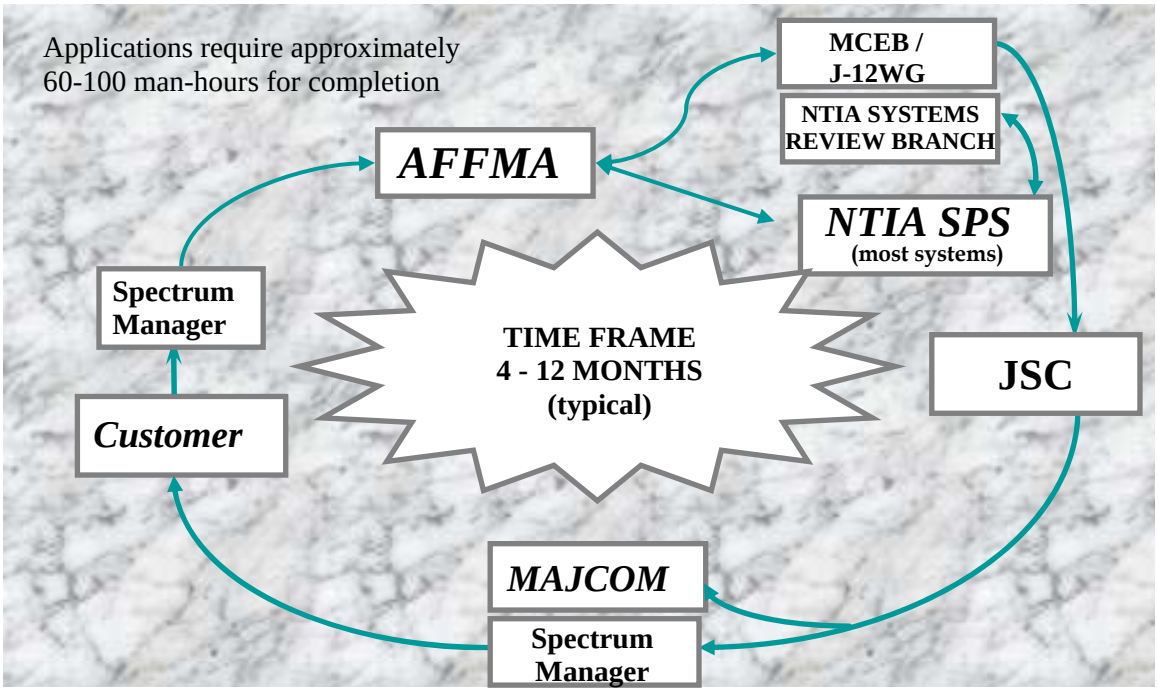

Figure 3 Air Force Spectrum Certification Process

It takes approximately 60 to 100 man-hours for a trained spectrum manager to complete a certification application once the manufacturer has provided complete and accurate information. It may take up to a year from a

manufacturer's original application to the completed application. This is too long for today's rapid development of systems.

The electromagnetic spectrum is broken out by frequency service. The breakout is agreed upon internationally at the World Radio Conference (WRC), and then nationally. In the U.S., this is decided by the NTIA and the Federal Communications Commission (FCC) by agreement with the other federal agencies. "In-band" refers to equipment that is operating in accordance with these frequency services. The average processing time of an in-band system is four to twelve months. Systems that are not in conformance with this allocation table or "in-band" can take years to get approved, if they are not disapproved.

Spectrum managers enter the application data that they receive from the manufacturers using the Spectrum Certification Software (SCS) which was produced by the JSC. Due to lack of funds, this software hasn't been updated since 1999. There is accompanying software called the SCS Analysis Tools which will analyze the data in accordance with the NTIA manual. This was also fielded by the JSC and hasn't been updated since 1996 (also due to lack of funds). Changes to the NTIA manual in the area of standards take place several times a year. Therefore, the analysis tools provide incorrect information, which in turn results in extended time to obtain system certification.

The NTIA has developed a new spectrum certification software called Equipment Location – Certification Information Database (EL-CID) which will address most of these problems. It may result in the application being done using

both software packages to ensure that the DoD equipment certification database stays current.

Another important element of spectrum certification is note-to-holders. A note-to-holder is an amendment to an approved DD Form 1494 application and its associated actions. Examples include:

- Adding another electronically identified device to an already approved application.
- Making a minor change or update to the information on the existing form.
- Updating the security classification markings of blocks on a page or on individual pages.
- Downgrading the entire application or replacing the security classification authority, reason for classification, and downgrading instructions.
- Adding an Air Force user to an existing Army or Navy application.
- Amending the nomenclature or application title.
- Amending the United States Military Communications Electronics Board (MCEB) comment to add or delete some portion of the observation, comment, or guidance.
- Providing all J/F 12 holders of relevant host nation comments.

Host Nation Support

Approval to activate RF equipment outside of the United States and Possessions (US&P) is required prior to deployment to any foreign country. The process begins with the preparation of a document, which has been approved for release by the originator's foreign disclosure office, and the transmittal of this documentation to the appropriate MAJCOM, and AFFMA. The "package" is then routed to the MCEB for distribution to the appropriate Combatant Commanders (CCDRs) and Joint Frequency Management Offices (JFMOs) for presentation and comment by the host nations identified in the coordination process.

The process to obtain host nation coordination can take up to three years dependent upon the complexity of the system and radio frequency band which

equipment will operate.. This process can not begin until AFFMA has approved the spectrum certification application which adds anywhere from four to six months to this exceedingly long process. Without this host nation approval, operation of radio-communications equipment, including low power equipment, could result in fines up to one million dollars, confiscation of equipment, and imprisonment for those operators using these systems. Ultimately, the operational mission could be endangered. The countries in which we operate expect us to realize that the frequencies we use in their territories are subject to their laws – the spectrum is a national sovereignty issue. For example, German Military Communications officials have stated that they want to retest our future aviation equipment because the data the United States has reported has been incorrect so many times. Host nation support is documented using the Host Nation Support Worldwide Database Online (HNSWDO) which is managed by the JSC.

Frequency Assignments

A radio frequency assignment (RFA) is the identification of and authorization to use a frequency, group of frequencies, or frequency band at a certain geographical location or area, for a specific purpose, for a specific time period, and under certain operating conditions.

Figure 4 Frequency Assignment Processshows the frequency assignment process for Air Force customers. The process begins with the customer identifying the need for an "assignment" to the base, center, or wing spectrum management office (at least six months prior to the start date of the requirement). The installation spectrum management office will compose this information into a

meaningful format and convey the request to the MAJCOM and the AFFMA. The AFFMA coordinates the need with other agencies at the national level and advises of approval, limited approval, or denial as early as possible before the requested start date.

The approval process typically takes from 45 days to 6 months in accordance with (IAW) AFI 33-118, Chapter 3.2. If the request is for use in a foreign country, the process takes a minimum four months to one year and must be preceded with a favorable host nation coordination document. This length of processing time often does not meet our military requirements, and the Military Services continue to work with NTIA and the IRAC Frequency Assignment Subcommittee (FAS) to reduce the processing times.

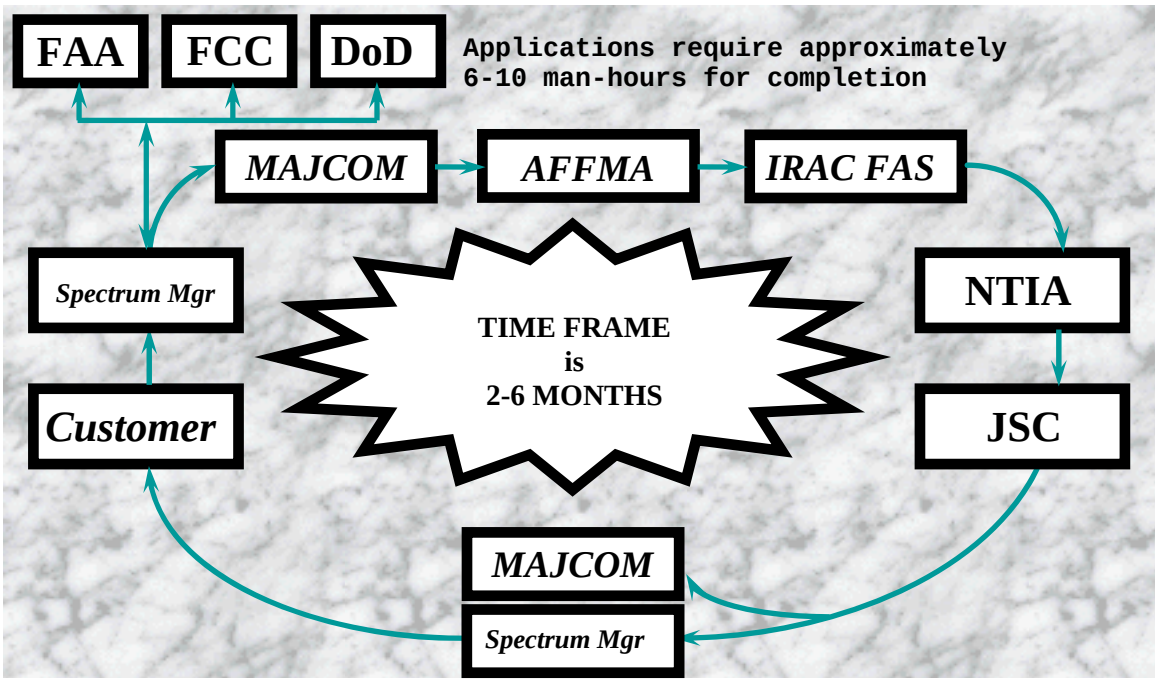

Figure 4 Frequency Assignment Process

The frequency proposal is entered into the Spectrum XXI software which was developed by the JSC from Service requirements. This software is used by all federal agencies to conduct create and manage RFAs. The software includes the approval cycle and results in an easily accessible database of approved RFAs for any area of interest that the user sets up the software to compile. It also has a very good engineering tool set for analyzing whether a frequency proposal will interfere with current assignments. It is useful in finding open frequencies that can be assigned and determines whether that assignment will support the stated requirement.

Electronic Attack (EA) Clearances

Within the United States and Canada the activation of Electronic Warfare (EW) capabilities (i.e. electromagnetic, directed energy, or anti-radiation weapons to attack personnel, facilities, or equipment with the intent of degrading, neutralizing, or destroying enemy combat capability) must be favorably coordinated with the users that could or would be adversely affected by the electronic warfare activity. EA clearances are handled IAW CJCSM 3312.01. The clearance request must be forwarded through command channels to the military FMO for coordination and approval at the national level, and the customer(s) must be aware that not all electronic warfare activity can be approved because of the interference potential to other users in the environment. When feasible, EW testing and training should be requested within military bands of the radio frequency (RF) spectrum so that the minimum amount of coordination with other government and federal agencies will be required. DoD ranges are given

limited authority to use some frequency bands (that are compatible with the environment). Requirements at bases and facilities not within a DoD test and training range must be forwarded through the installation (base/center) and MAJCOM channels. EA clearances are limited to a period of time not to exceed one year.

Joint Spectrum Interference Resolution (JSIR) Program

The JSIR program addresses Electromagnetic Interference (EMI) and EW interfering with a DoD mission (training or operational). The program is coordinated and managed by the JSC in Annapolis, Maryland. JSIR is centrally managed; however, the implementation is distributed among various service components (CJCSM 3320.02A, Joint Spectrum Interference Resolution Procedures, 2006)

The JSIR process is intended to resolve EMI events at the lowest level. When available, spectrum managers become involved to assist organizations, in trying to determine where the causes of EMI by consulting the radio frequency management database for their area (usually found in Spectrum XXI). When the issue cannot be resolved locally, it is referred up the spectrum management chain of command with each higher level attempting resolution. If the interference cannot be resolved at the service headquarters level, further JSIR support can be requested in the report. The JSC tracks the status of interference reports, results, and inputs the information into their database. When interference problems effect operation in the battlefield, the Joint Staff in concert with the services will decide on the proper course of action and assigns a lead agency to bring the EMI incident

to successful resolution. The JSC publishes a listing of open JSIRs every third quarter of each fiscal year. CCDRs, Services, and agencies annually review open JSIRs and decide on the appropriate resolution (close, further investigations, or engineering assistance).

Air Force Spectrum Interference Resolution

The Air Force Spectrum Interference Resolution (AFSIR) program is the Air Force's portion of the JSIR program which was established by the DoD in 1992 as a replacement for the electromagnetic interference portion of the former DoD Meaconing, Intrusion, Jamming, and Interference (MIJI) program. The focus of the MIJI program was to report potentially hostile EW attacks against U.S. military systems. The AFSIR and JSIR programs are structured to resolve interference incidents at the lowest possible level, using component organic resources to resolve interference incidents where possible. Those incidents that cannot be resolved locally are referred up the chain of command, with resolution attempted at each level. If the interference incident cannot be resolved by the affected DoD Component or the service engineering agency responsible for spectrum interference resolution, then it is referred to the JSC JSIR office for resolution.

The spectrum manager will coordinate with and assist the user to insure the information is provided as required. They will use Spectrum XXI to identify where the source of interference and if possible resolve the interference quickly.

Joint Restricted Frequency List (JRFL)

According to JP 1-02, Department of Defense Dictionary of Military and Associated Terms, JRFL is:

> *A time and geographically-oriented listing of TABOO, PROTECTED, and GUARDED functions, nets, and frequencies. It should be limited to the minimum number of frequencies necessary for friendly forces to accomplish objectives.* (Joint Publication 1-02, 2001).

The JRFL lists friendly transmit frequencies of our ground, sea, and air forces, transmit frequencies of our multi-national forces, frequencies of news agencies in our area, enemy frequencies that we do not want to jam because of their intelligence value, and frequencies that can be jammed freely. It is time oriented because different operations will require different frequencies depending on the phase of the operation and who is operating in the region. The amount of frequencies and times at which we are using them can also be used as part of a military deception plan. The J-6 Communications Directorate has the responsibility for disseminating the JRFL and therefore needs professional spectrum managers who know joint operations and understand how to work with all the communities in a very dynamic environment.

The JRFL establishes the minimum number of frequencies for our friendly forces to accomplish objectives. Consequently, the JRFL permits the minimum number of restrictions on EW systems such as EC-130H/COMPASS CALL and EA-6B/PROWLER. The JRFL should be compiled based on the coordinated inputs from the operations, intelligence, and communications staffs within the command and affected subordinate commands. The J-6 spectrum managers

should ensure that the unit frequency assignments chosen for inclusion as PROTECTED or TABOO on the JRFL are submitted to the J-3 Operations Directorate for final approval prior to release. The J-3 can remove the restrictions imposed by the JRFL if they determine that the benefit of jamming a restricted frequency other immediate needs by friendly forces. The intelligence functions must be consulted before this decision. Self protection of combat aircraft and ships has priority over all our other frequency requirements in the JRFL. Joint Pub 3-13.1 defines GUARDED, PROTECTED, and TABOO frequencies as follows (Joint Publication 3-13.1, 2007):

- "GUARDED frequencies are adversary frequencies that are currently being exploited for combat information and intelligence. A GUARDED frequency is time-oriented in that the list changes as the adversary assumes different combat postures. These frequencies may be jammed after the commander has weighed the potential operational gain against the loss of the technical information."

- "PROTECTED frequencies are those friendly frequencies used for a particular operation, identified, and protected to prevent them from being inadvertently jammed by friendly forces while active EW operations are directed against hostile forces. These frequencies are of such critical importance that jamming should be restricted unless absolutely necessary or until coordination with the using unit is made. They are generally time-oriented, may change with the tactical situation, and should be updated periodically."

- "TABOO frequencies are any friendly frequency of such importance that it must never be deliberately jammed or interfered with by friendly forces. Normally these include international distress, CEASE BUZZER, safety, and controller frequencies. These are generally long-standing frequencies. However, they may be time-oriented in that, as the combat or exercise situation changes, the restrictions may be removed to allow self protection by friendly forces. Specifically, during crisis or hostilities, short duration jamming may be authorized on TABOO frequencies for self protection to provide coverage from unknown threats, threats

operating outside their known frequency ranges, or for other reasons."

Doctrine

> *Military operations are executed in an information environment increasingly complicated by the electromagnetic spectrum.* (Joint Publication 3-13.1, 2007)

Doctrine is perhaps the most ignored area within spectrum management. This is perhaps due to the limited understanding of how spectrum management works within the Joint environment. As stated in Chapter 1, the OASD and USSTRATCOM J-8 Network & Spectrum Management Functional Solutions Analysis called for strengthening of spectrum management doctrine. Most specifically they called for the creation of Joint Tactics, Techniques, and Procedures (TTP) for Spectrum Management. Joint Publication 3-13.1, Joint Doctrine for EW, is the only true doctrine publication on spectrum management. This makes it seem that spectrum management is an element of EW, when in reality EW is only one of many elements that spectrum management supports.

JP 1-02, Department of Defense Dictionary of Military and Associated Terms, states that the battlespace is

> *The environment, factors, and conditions which must be understood to successfully apply combat power, protect the force, or complete the mission. This includes the air, land, sea, space and the included enemy and friendly forces, facilities, weather, terrain, the electromagnetic spectrum, and information environment within the operational areas and areas of interest.* (Joint Publication 1-02, 2001)

As seen in this definition, the electromagnetic spectrum is an important part of the battlespace.

Since JP 3-13.1 is the main doctrine for spectrum management we will start the research on the critical doctrinal elements there. JP 3-13.1 sites the following policy from the Chairman of the Joint Chiefs of Staff Instruction (CJCSI) 3220.01, which requires that all CCDRs are required to observe,

> *To establish a frequency management structure that includes a JFMO and to establish procedures to support planned and ongoing operations. The supported CCDR authorizes and controls use of the spectrum resources by the military forces under his or her command.* (Joint Publication 3-13.1, 2007).

Each CCDR is responsible for issuing a command policy on how the spectrum is used in their area of operation, coordinate and gain host nation clearance for use of the spectrum, and ensures that the military forces are authorized needed frequencies to execute their missions. The CCDR accomplishes this task by establishing a JFMO, typically under the authority of the J-6, to support necessary planning, coordination, and control of the spectrum for assigned forces. The JFMO must be staffed with highly experienced spectrum managers in joint forces operations.

Figure 5 shows the spectrum management process followed by the JFMO. Planning is an important element of spectrum management, appearing in items 1, 2, 5, and 10. However, planning should begin well before the deployment or operations begin, as shown in Figure 6 JTF Spectrum Management Planning Flow Diagram

(Joint Publication 3-13.1, 2007), which shows a JTF spectrum management planning flow diagram.

Figure 5 JFMO Spectrum Management Process
(Joint Publication 3-13.1, 2007)

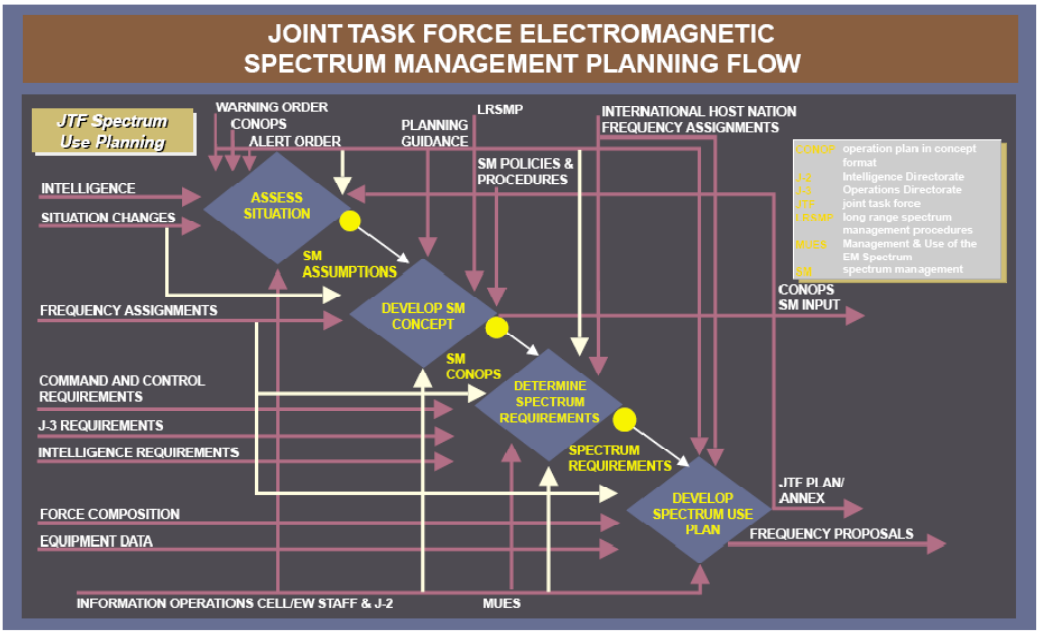

Figure 6 JTF Spectrum Management Planning Flow Diagram (Joint Publication 3-13.1, 2007)

Figure 6 essentially depicts a traditional observe, orient, decide and act (OODA) loop. Coordination and negotiation are among the most important attributes of a spectrum manager. Coordination and negotiation must begin before any element of the exercise or operation. The spectrum does not belong to the military; the military shares it with many others. This is more important when the military are operating in a foreign country and are attempting to use their resource.

Observation takes place in equivalent military spectrum management office and/or the foreign Ministry of Communications offices. Through electronic observation more frequencies are identified, which the DoD share with the foreign government. In some countries the spectrum management is so primitive that the US military establishes the host nation's spectrum management database which is

left with them when the US military forces depart. Primarily, personnel assigned to the Joint Staff Operations Directorate (J-3), Intelligence Directorate (J-2), Strategic Plans Directorate (J-5) and Communications Directorate (J-6) plan, coordinate and control joint military use of the electromagnetic spectrum.

The RF environment constantly changes as new forces deploy and as new applications and systems are fielded. All elements of EW (deny, disrupt, protect, and monitor) play a major role is the spectrum management planning and execution during the operations. Figure 7shows the execution of frequency changes when conflicts occur during wartime.

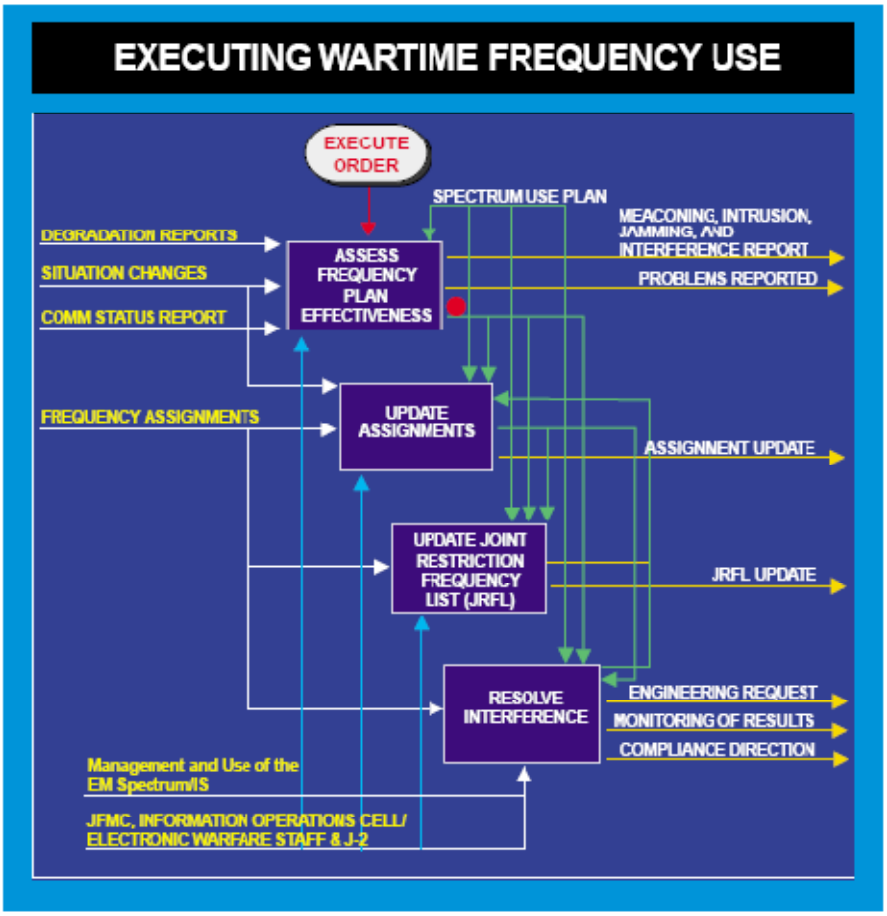

Figure 7 Executing Wartime Frequency Use
(Joint Publication 3-13.1, 2007)

By exercising a complete JRFL and an effective emissions control (EMCON) plan, EW operations are effective without compromising battlespace safety and security. Frequency deconfliction is a continuous spectrum management requirement. There are many users who do not have well-identified, prioritized spectrum requirements, and available spectrum is limited. Examples include unauthorized and/or unplanned RF devices in the operating area, multi-national partners who do not disclose all of their spectrum requirements, and the adversary's use of the spectrum (communications and/or jamming). Figure 8 shows the critical elements in the EW frequency deconfliction process.

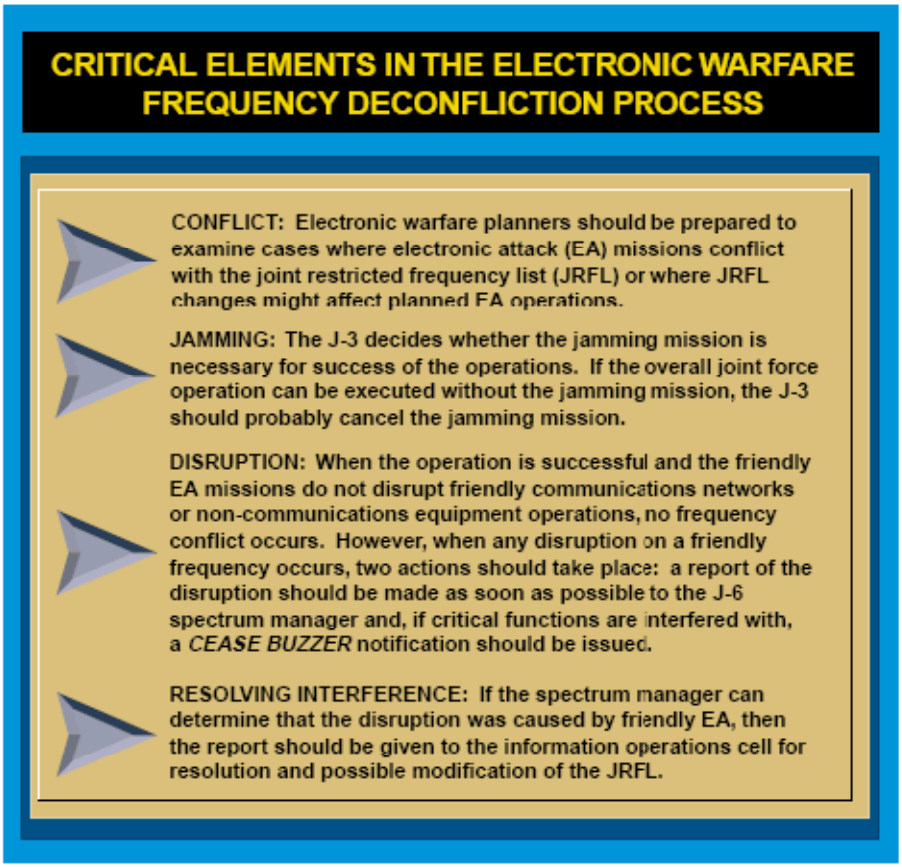

Figure 8 Critical Elements in EW Frequency Deconfliction Process (Joint Publication 3-13.1, 2007)

Joint Pub 6-0, Joint Communications Systems, states the specific functions of network control are (1) Technical management and direction, and (2) Management of C4 resources (e.g., C4 personnel, equipment, maintenance, logistics, and management of the radio frequency spectrum). The network control function provides technical management of system configuration, resources, performance, fault isolation, security, engineering and system planning. Spectrum management is identified by JP 6-0 as a critical step in the network control function.

JP 6-0 also states that spectrum management is a crucial factor in joint operations due to the complexity and vast distances involved in joint warfighting. Spectrum management is fundamental because frequencies are required in operating all electromagnetic communications. As stated earlier, frequency usage is governed by international law. Frequency usage must be coordinated on a continuous basis at tactical, operational, and strategic levels using national and international channels. The Combatant Command and Department of State are often crucial in communicating with some foreign governments. Close and continuous coordination between spectrum managers and C4 system planners is crucial to ensure access to the electromagnetic spectrum. (Joint Pub 6-0, 2006)

Organizations

OASD and USSTRATCOM J-8 were correct when they stated that there is limited assured access to the spectrum. The spectrum is a national resource that is controlled by the nation over which it can be seen (only inner space), sea lanes and land. The spectrum does not fit well within distinct national borders therefore

international agreements are necessary to meet our national requirements for spectrum.

International Telecommunication Union (ITU)

The ITU is the agency designated by the United Nations to coordinate international telecommunications standards and regulations. Figure 9 shows the ITU's organization.

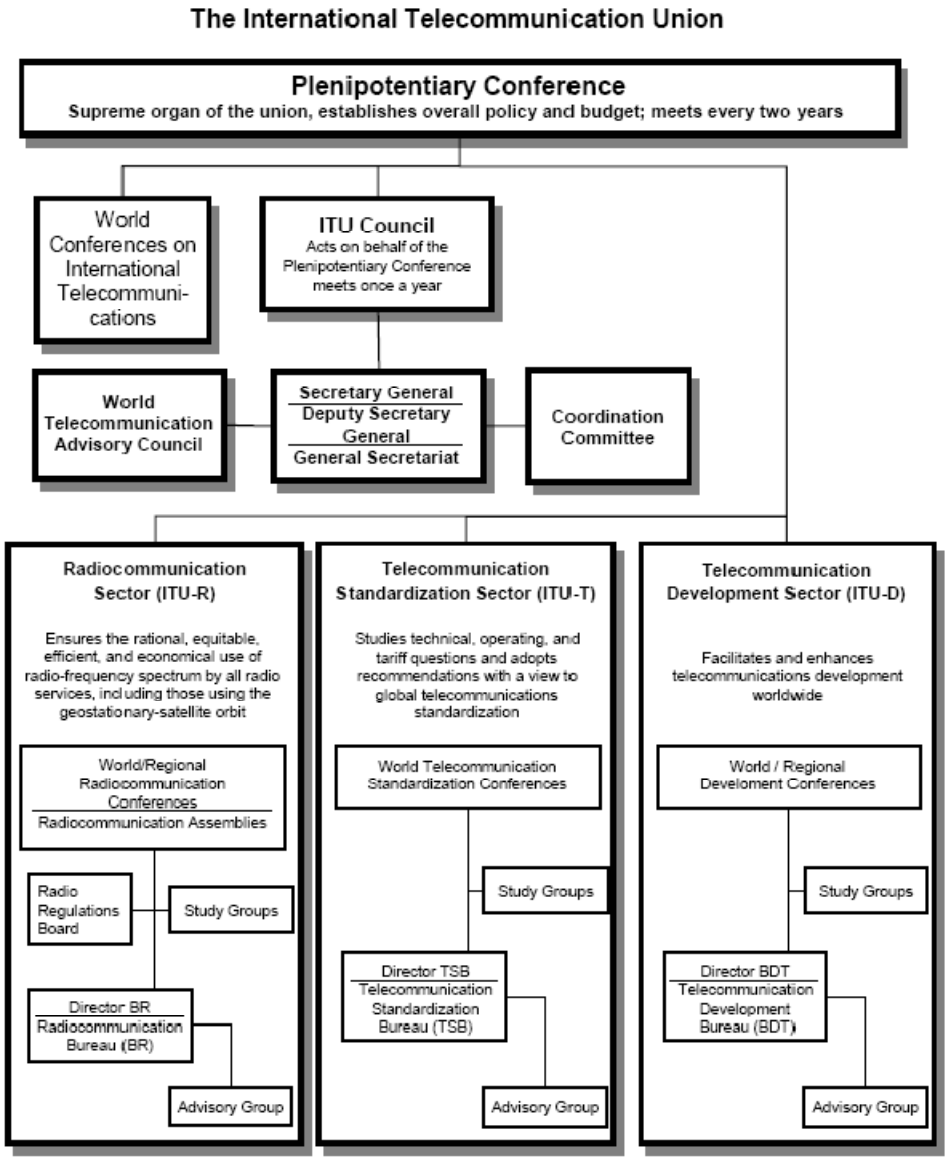

Figure 9 ITU Structure (Portigal, 2004)

The ITU consists of 189 member nations (Figure 10). The Radiocommunication Sector, ITU-R, is responsible for all issues within radio communications and spectrum management. The World Radio Conferences (WRCs) are the main venues where the world representatives meet together to allocate the international RF spectrum. Each member nation has single voting, and a third world nation has the same voting power as the United States. The US delegate has the status of Ambassador which is important since the results of these WRCs results in treaties with the international community.

Figure 10 ITU World Radio Conference (Moorefield, 2006)

The Radiocommunications Bureau, ITU/BR, is responsible for registering frequency assignments and maintaining the master international frequency register. The ITU/BR also coordinates upcoming systems and assists in resolving interference. Following the WRC, the ITU publishes the radio regulations (RR), which is the international rules and regulations for spectrum use. These radio regulations have worldwide effect except where regional or national requirements

differ and regional members agree to these differences. The Figure 11 illustrates the three recognized regions of the world.

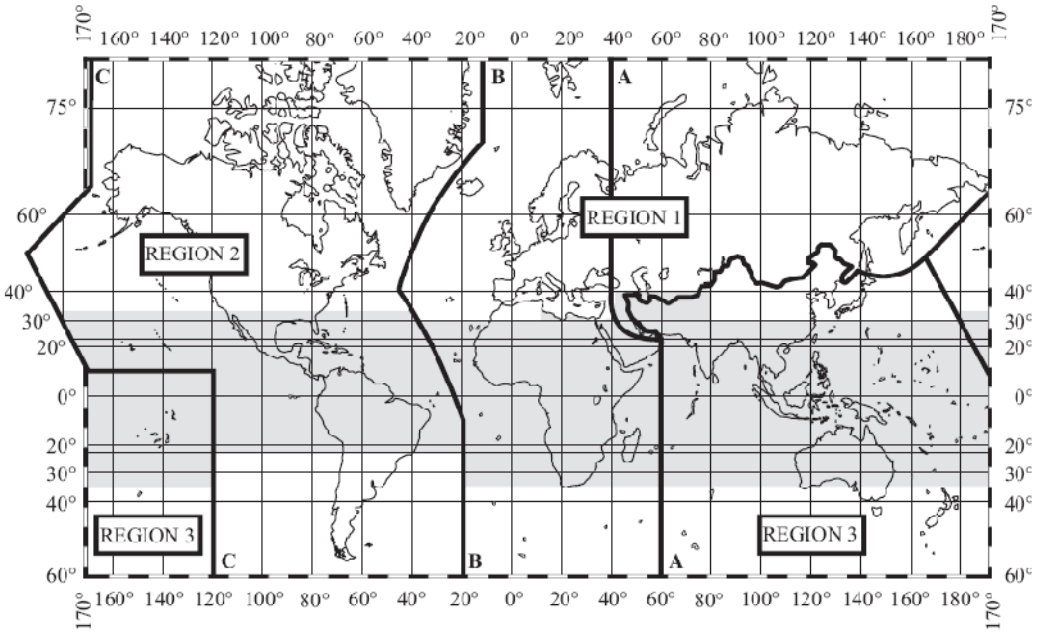

Figure 11 ITU Worldwide Regions (Portigal, 2004)

National Organizations

Nations retain sovereign power over the use of spectrum in their country and may operate systems in accordance with section 4.4 of the RR, provided they do not cause and are willing to accept interference (Portigal, 2004). U.S. National spectrum policy is governed by the Communications Act of 1934. The Communications Act of 1934 was established to resolve the confusion over which government agencies controlled the different elements of communications. The Communications Act of 1934 created the Federal Communications Commission (FCC) as the single agency to manage commercial communications.

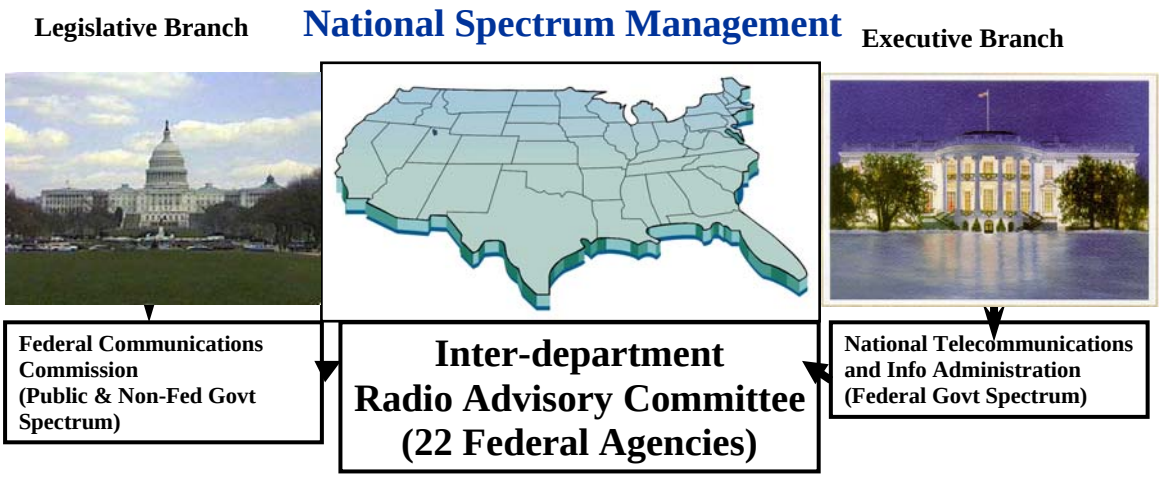

Figure 12 National Spectrum Management (Moorefield, 2006)

The responsibility of managing federal government frequencies was given to the President. The IRAC, first created by Herbert Hoover in 1922, serves as the practical body to manage frequency use. (Portigal, 2004) The IRAC now falls under the National Telecommunications and Information Administration (NTIA).

In 2006 at the urging of Congress, the Government Accounting Office (GAO) conducted a study to look at combining the FCC and NTIA. The study was called "Options for and Barriers to Spectrum Reform." The fear in Congress was that the current organizational structure might hamper effective and timely utilization of the spectrum. The GAO report stated that the current structure poses barriers to spectrum reform because neither the FCC nor NTIA has complete control over the situation. An outcome of the GAO report was a call for the development of a national spectrum plan that would examine the current state of US spectrum management (Hecker, 2006).

It is the author's opinion that the current structure for spectrum management in the United States works well and should not be changed. It functions much like our government in which the FCC and NTIA serve to provide the necessary checks and balances for the communications needs of our nation. If the organizations were merged either commercial interests or federal government needs would dominate national communications policy. The military has been able to defend its spectrum interests from the first auctions in 1993 through today. A single communications organization would most probably support commercial interests. This is evidenced in countries like the United Kingdom and Japan where one agency is responsible for both commercial and military communications policies. The military in both nations take a second place to commercial requirements.

Federal Communications Commission (FCC)

The FCC is mostly known for its regulation over radio and television; however, it has the major responsibility for overseeing licensed amateur radio and un-licensed low power devices (garage door openers, personal wireless devices, wireless LANS, wireless phones, etc.). The FCC also takes part as a non-voting member of the Interdepartmental Radio Advisory Committee and sub-committees (discussed in the next section).

National Telecommunications and Information Administration (NTIA)

President Kennedy created the NTIA as the responsible agency responsible for all federal government communications and folded the IRAC into the NTIA. President Carter subsequently placed NTIA under the Department of

Commerce. Regardless of the organizational changes, the IRAC remains the primary committee responsible for all areas of the federal government's electromagnetic spectrum management. Figure 13represents the IRAC council of 18 representatives, one liaison (FCC) and the chairman provided by NTIA.

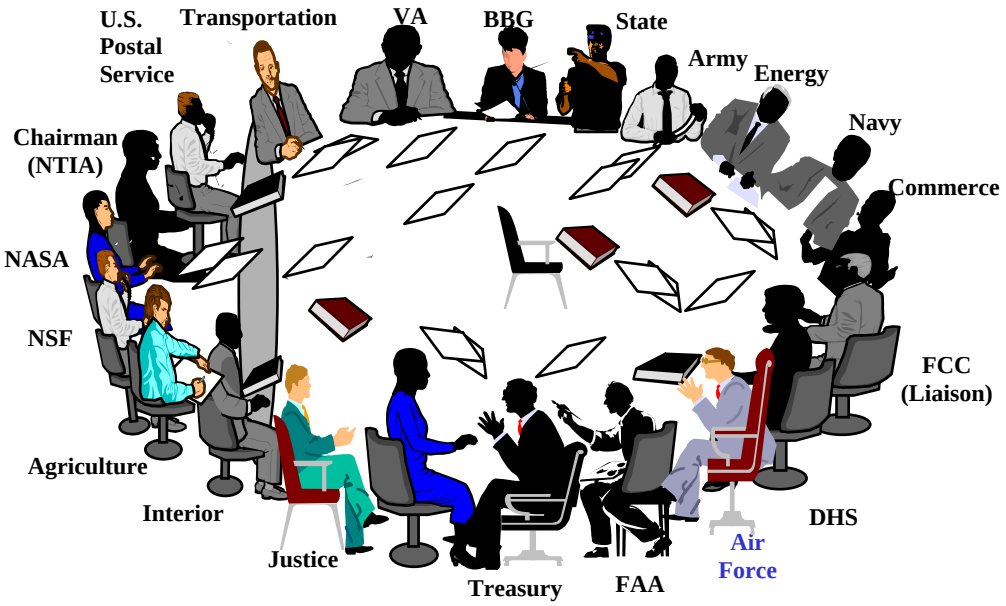

Figure 13 IRAC Council (Moorefield, 2006)

There are four permanent subcommittees of the IRAC: Frequency Assignment (FAS), Technical (TSC), Spectrum Planning (SPS), and International Notification Group (ING). The FAS is responsible for frequency assignment approvals. The TSC is responsible for creation and modification of technical standards for systems. The SPS is responsible for spectrum certifications. The ING works with the ITU and international working groups to notify the ITU on assignments, space, and other international issues. The IRAC approves or disapproves items coming from the permanent subcommittees and discusses important national spectrum management issues. Their actions result in changes

to the NTIA Manual of Regulations and Procedures for Federal Radio Frequency Management – the technical rules and standards of National Spectrum Management. The manual is available on NTIA's website.

Department of Defense (DoD)

The Military Departments, Combatant Commanders, and other Defense Agencies are responsible for spectrum management within the DoD. This paper will only discuss the primary regulations/instructions for each of the military services and their primary spectrum management offices. DoD Directive (DoDD) 4650.1, Management and Use of the Radio Frequency Spectrum, dated 8 Jun 2004, is the DoD's regulation on spectrum management. Its primary purpose is to establish the services spectrum management programs (Section 5.5). One item in this directive that is often not performed is,

> *No-spectrum-dependent system shall proceed into the Production and Deployment Phase without such a spectrum supportability determination unless specific authorization to proceed is granted by the Under Secretary of Defense for Acquisition, Technology, and Logistics (USD(AT&L)) or a waiver is granted by the Assistant Secretary of Defense for Networks and Information Integration (ASD(NII)).* (DODD 4650.1, 2004).

Unfortunately, this directive is very difficult to follow; the length of the spectrum certification approval process described earlier would push back system development by a minimum of one year. Waivers are often not enforced, and acquisition program managers may see this mandate as unacceptable in an era of fast paced acquisitions (18 months or less).

MCEB

The MCEB is the coordinating agency for spectrum certification and host-nation coordination. It is the major communications coordination agency between elements of the DoD and outside agencies. For spectrum management this is mainly an administrative function whose leadership and members are derived from the service spectrum management offices. The Joint Frequency Panel (JFP) is the principle coordinating agency for spectrum management. The JFP reviews, develops, coordinates, implements various studies and reports and makes recommendations in the areas of spectrum engineering and management. MCEB Publication 7 is the major data dictionary on how to create frequency proposals for all military services.

Army

Army spectrum management is composed of two main elements: Army Communications-Electronics (C-E) Services, located in Arlington, VA, and the Army Frequency Management Office (AFMO) Continental United States (CONUS). Army C-E Services is responsible for Army Spectrum Policy, coordination with NTIA and the other military departments, participation in MCEB frequency panels, and all spectrum certification requirements. US Army Europe (USAREUR), US Army Pacific (USARPAC), US Army Central (USARCENT), and US Army South (USARSO) have spectrum management organizations which provide similar support for outside CONUS (OCONUS) operations. These OCONUS spectrum management offices work through the CCDRs of their respective theater of operation.

Army Regulation (AR) 5-12 Spectrum Management is the guiding spectrum management publication for the Army. AFMO CONUS also provides a guide called AFMO Standard Frequency Action Format (SFAF) guide which provides guidance on submitting frequency proposals.

Navy

The Navy's spectrum management office is the Navy and Marines Corps Spectrum Management office in Alexandria, VA. They are responsible for Navy spectrum policy, plans, frequency assignments and spectrum certification. They also perform close coordination with NTIA and the other military service spectrum offices.

OPNAVINST 2400.20E, Navy Management of the Radio Frequency Spectrum, dated 19 Jan 1989, is the primary Navy's instruction for spectrum management for the Navy and the Marine Corps. (OPNAVINST 2400.20E, Navy Management of the Radio Frequency Spectrum, 1989) The Marine Corps supplemented the Navy Instruction with Marine Corps Order 2400.2, Marine Corps Management of the Radio Frequency Spectrum, Dated 16 Jun 89. (Marine Corps Order 2400.2, Marine Corps Management of the Radio Frequency Spectrum, 1989)

Air Force

The Air Force Spectrum Management Organization is quite different from the Army and the Navy. The Air Force Frequency Management Agency (AFFMA) does the jobs of Army CE Services and AFMO CONUS with the exception that each Air Force MAJCOMs' has a spectrum management office that

handles certification papers and frequency assignments before forwarding them to AFFMA. The overseas Air Force MAJCOMs also support the CCDR of their theater.

The primary Air Force publication on spectrum management is Air Force Instruction (AFI) 33-118. The Air Force also publishes a publication on how to prepare frequency proposals and important information on spectrum certifications.

Training

Training is an essential ingredient to staffing any field with the people required to get the job done. It is even more important when the field of study is highly technical, and changes in the technology are continuous. This paper has discussed spectrum management from a non-technical basis to ensure an understanding by a wider audience; however, many of the aspects of spectrum management are highly technical and continuously changing.

Effective spectrum managers, need to understand a myriad of communications systems, radars, and sensors. They must be able to analyze weather anomalies, solar flares, and other elements which would affect system operations. They must have familiarity with large volumes of government regulations, host nation laws and mission requirements and provide users with the best solution to meet their requirements.

No single school can hope to provide the necessary skills to educate people into spectrum management especially in light of smaller military budgets and limited time frames to complete the training. Lifelong learning is required.

This paper will only consider the NTIA and Air Force Training programs. The Army only has a spectrum management training program; however, limited time prevented the investigation of their program.

NTIA Radio Frequency Spectrum Management Seminar

NTIA holds their spectrum management training seminar twice a year. It is intended to train non-DoD federal spectrum managers in the basics of spectrum management. While this training seminar is not intended to train DoD spectrum managers many DoD personnel attend the seminar to get a better insight into NTIA and other federal agencies spectrum management. The training seminar lasts four and one half days. It covers the following areas:

- Introduction to Spectrum Management and Terminology
- The Federal Communications Commission
- The President's Spectrum Policy Initiative
- National Telecommunications and Information Administration
  - The IRAC: Spectrum Management policy and procedure
  - Spectrum Planning Subcommittee and Spectrum Certification
- Federal Aviation Administration Air Traffic Control Spectrum Engineering Services
  - Transmission Propagation
- International Aspects of Spectrum Management and U.S. WRC Preparatory Processes
- Spectrum Management of Space Services
- Microwave Engineering, Land Mobile and Other Services
- NTIA Emergency Planning and Public Safety
- Frequency Assignment Subcommittee: VHF/UHF Narrowband Federal Policy
- Future of Spectrum Management
- Future of Automated Spectrum Management
- Technical Subcommittee: Radar Spectrum Engineering Criteria
- U.S. Military Spectrum Management
- Current Opportunities and Challenges in Spectrum Management

This is a very good program to achieve NTIA's objective of spectrum management orientation. (Veader, 2007)

Electromagnetic Spectrum Management Course (ESMC)

ESMC is an education course for all DoD spectrum managers which is provided by the Air Force Air Education and Training Command (AETC) at Keesler AFB, MS. For the Air Force this course is only available through re-training and is not available for first term airmen. The personnel attending are also supposed to come from a communications-electronics specialty; however, this requirement has been waived many times. ESMC is attended by students from all allied nations, including personnel from the new Iraq. The course lasts four months and includes the following areas:

- Electromagnetic spectrum management introduction
- Spectrum management mathematics
- Communications-electronics engineering principles
- Communications systems engineering
- Principles of communications systems
- Principles of electromagnetic spectrum administration
- Introduction to afloat electromagnetic spectrum operating program
- Introduction to system planning engineering and evaluation device
- Introduction to spectrum XXI program
- Introduction to joint automated communications-electronics operating instructions systems (JACS)
- Principles of joint spectrum management

The US Air Force (USAF) is increasing its spectrum manager enlisted billets by 102 over the next two years. This will place an ESMC school-trained frequency manager at every Air Force base. Two immediate bonuses to the addition of these new spectrum managers are that (1) spectrum management will

no longer be just an additional duty, and (2) the quality of frequency proposals should improve.

Joint Task Force (JTF) Spectrum Management Course

The JTF Spectrum Management Course is also provided by AETC. It is a three week course intended to teach experienced spectrum managers on spectrum management in the JTF environment. This course covers the following areas:

- Principles of joint electromagnetic spectrum administration
- Spectrum management in the joint environment
- Spectrum analyzer training for DF
- Advanced Communications systems engineering
- Advanced JACS training
- Training in numerous tools and spectrum management procedures

Materiel

Spectrum management materiel consists of software programs and self-contained databases. This paper will cover only the NTIA and Joint Spectrum Center provided software and databases.

JSC Software Programs

JSC used to be the Electromagnetic Compatibility and Analysis Center (ECAC). They have been the major provider for DoD spectrum management software for the last 30 years. They have also built the latest software for NTIA.

Spectrum XXI

SPECTRUM XXI is a client/server, Windows-based software application. It is the predominant spectrum management application in the federal government. It provides spectrum managers with a single information system

that addresses most spectrum management automation requirements. Spectrum XXI supports operational planning for JTF operations as well as near real-time management of the radio frequency spectrum anywhere in the world. Its major emphasis is on assigning compatible frequencies and performing spectrum engineering on a multitude of situations. Interconnected through the Secure Internet Protocol Router Network (SIPRNet), the software extends connectivity to civilian, military, and federal spectrum management entities (Spectrum XXI, 2008).

HNSWDO

HNSWDO is a web application that provides the host nation status on DoD systems. If equipment and/or systems do not have host nation approval they can't be brought into that country. Often equipment and systems will have host nation approval with restrictions (i.e., power, frequency band, etc.). The HNSWDO aids in the deployment of communication systems for the warfighter. It also provides worldwide visibility of the RF spectrum for host nations. One of HNDSWDO's major features is that it automates distribution of host nation coordination requests and CCDR's submission of host nation supportability comments which significantly reduces the time required to manage the process. The HNSWDO application provides users with near real time updates and greatly reduces the process improvement time from years to months (HNSWDO, 2008).

Spectrum Certification Software (SCS)

SCS is a Microsoft Windows software application which creates DoD spectrum certification applications using the DD Form 1494. SCS makes use of a

database which allows for the complete storage and retrieval of all J/F-12s (MCEB numbering system for DD Form 1494s). It updates the database with created DD Form 1494s generated on the local computer and synchronizes monthly with the main database. It has an effective query system which helps the user in identifying systems that match user requirements. Its final capability is the ability to download elements of the DD Form 1494 application to the SCS Analysis Tools Application. It is an easy software application to learn; however, the DD Form 1494 is being replaced by EL-CID.

SCS AT

SCS AT is a Microsoft Windows software application which allows for the spectrum analysis of DD Form 1494s and a limited analysis of radar spectrum engineering criteria (RSEC), frequency modulation (FM), amplitude modulation (AM), and pulse-code modulation (PCM) systems against NTIA standards. The program has many faults and hasn't been updated since 1992, difficult to use and has no help system. This system won't be needed since EL-CID includes an analysis feature.

EL-CID

EL-CID is a Microsoft Windows application for US federal government spectrum management. It was developed to provide an automated tool to support electronic processing of spectrum certification requests at NTIA. It will replace SCS eventually once it meets the major needs of DoD spectrum management. It currently does not support foreign disclosure processing for host nation approval. The NTIA Office of Spectrum Management (OSM) data dictionary is a new

comprehensive database which supports EL-CID. This new system will greatly improve and speed up the spectrum certification process because once an element (transmitter, receiver, antenna, location) is approved it never has to be re-approved. The current spectrum certification process requires the approval of all elements of the system regardless that many of the elements were approved in the past.

Databases

There are many databases which provide information to the spectrum manager; however, there are only two databases which provide daily information to perform major spectrum elements besides the databases in Spectrum XXI , HNSWDO, and SCS.

GMF

GMF is an acronym for government master file. It is a legacy application that maintains confidential information on federal government frequency assignments within the U.S.. The GMF is difficult to use (outdated user interface) and is not intuitive. The NTIA OSM database is replacing the GMF.

DMR

The DMR is a Microsoft Windows application which updates the J/F 12 database (DD Form 1494) with the approved spectrum certification applications and/or note-to-holders. The DMR is distributed by JSC regularly to designated spectrum management personnel. The data file contains US Secret classified information, so recipients must be able to properly store and use these CDs. The DMR does not require any changes.

III. DoD Spectrum Management – Recommendations

This chapter identifies recommendations for problem areas identified in Chapter 2.

Spectrum Elements

Spectrum Allocation and Allotments

DoD allotments must be able to be changed easily to meet the needs of the military services. An email sent from spectrum manager responsible for an installation should be able to request an exception to the allotment plan with justification. If justification is sufficient, the military service FMO will contact the owner of the allotment (other military service) and gain an exception immediately. If the justification for allotment change is insufficient, the military service FMO should identify problem areas or request additional justification to facilitate approval or make other recommendations.

Spectrum Certification

As stated in chapter 2, spectrum certification is the foundation of the spectrum management. There are no easy fix recommendations for the problems in spectrum certification. It is going to require research and study. The AFFMA has begun work with DISA, NTIA, the other military services, and the acquisition community to develop a way ahead but this effort was never completed. Some of the recommendations that came out of these meetings were started and since dropped.

One recommendation is that these meetings for change be restarted and establish binding resolutions by all the parties. Recommendations that are established and later shelved provide no relief to the problem.

Fixing these problems will require effort and long term commitment. Major cracks in a structural foundation cannot be repaired with cosmetic or temporary effort. Solutions will involve more people at many locations dedicated to performing spectrum certification. The people can and should be DoD civilians to work all DoD requirements. The reason for DoD civilians in these slots are that spectrum certification is a long term effort that requires experience beyond a typical military career. The individual services have duplication on spectrum certifications that can be avoided by having a central group perform the spectrum certification element. The people that are required should be geographically assigned worldwide to increase the visibility and provide immediate assistance in the completion of these spectrum certification applications.

Frequency assignments have a five year or ten year review, depending on band, of each frequency assignment. A review process needs to be established for spectrum certifications.

Air Force Lt General Donohue spoke at the AFFMA worldwide meeting in 2002 about changes to the acquisition program. One of his recommendations was to have acquisition program managers graded on spectrum management. No one has ever been able to bring this recommendation to reality. It cost the B-2 program office six billion dollars to fix problems they did not properly address

from early spectrum guidance. There are thousands of systems that have been purchased by the DoD that have not gained spectrum approval which have forced these systems to be put away in warehouses. This money cannot be recouped. If program managers were graded these travesties in program financial management would stop.

Frequency Assignments

The frequency assignment process must be shortened to provide quick service to the warfighter. The current system only allows for expedited requirements to receive a ten day approval cycle. The normal cycle takes approximately 45 – 60 days. The fix for this problem is to require less people involved in the approval process. Currently, there are 18 members of the FAS that have to approve the assignment proposals. Many offices are undermanned, with many workers having no alternate. If they are out of the office, no one is left to handle the paperwork.

The IRAC should consider changing the FAS process to minimize delays due to personnel absences. The number of people that need to approve frequency proposals should be limited. This will greatly shorten the approval time. The major agencies of concern are the FCC and the FAA.

JSIR/AFSIR

There should be a single, standard program for the DoD and that should be the JSIR. Having each service managing the program lessens the effectiveness of the overall program. The manager of the JSIR should be the JSC. The JSC

should be able to identify to the military service FMO the need for on-site assistance. The JSC needs to develop an easy to use program that will take away the reluctance to use the program. Reporting requirements should also be simplified.

Finally, the military services should maintain a funding level to handle required on-site assistance for interference/jamming problems. The services will also need to have a sufficient cadre of people with proper skills to identify and eliminate the interference/jamming problems.

Doctrine

Tactics, techniques, and procedures (TTP) need to be created for spectrum management. This was already identified by the OASD and USSTRATCOM J-8 Network & Spectrum Management Functional Solutions Analysis. It is estimated that it can be completed by 2011. The following areas need to be covered in the TTP:

- JTF Planning
- Advanced party procedures for identifying existing frequency usage in foreign government
- Coordination procedures with foreign government representatives
- Establishing areas of interest in concert with Operations and Intelligence personnel
- Establishing base of operation
- Ensuring proper spectrum management personnel (number and qualifications) – JTF training, spectrum management experience
- Establishing Spectrum XXI database
- Establishing JACS
- Building JRFL
- Establishing frequency deconfliction procedures
- There are many more areas that should be included (further study needed)

Training

Despite the training course we need to develop a corps of civilian instructors who can provide continuity and teach the enlisted instructors on spectrum management education. This is one of the lessons that the Army school has implemented to improve their education. The intent is not to entirely eliminate the military instructors because being an instructor is one of the best ways to grow future leaders and experts in the spectrum management career field.

Spectrum certification education is a must. Hopefully the DoD will build a corps of people that will create spectrum certification applications in the future. This will not encompass all the military needs; there will still be requirements for equipment at local installations. The installation spectrum manager will still need to know how to prepare a basic spectrum certification application.

Materiel

EL-CID covered in chapter 2 is the way for the future for spectrum certification applications. It also takes care of replacing the very outdated GMF database with the OSM data dictionary which is included in EL-CID. The future of DoD spectrum management software is Global Electromagnetic Spectrum Information System (GEMSIS). It provides the framework for the development and integration of capabilities to manage and use spectrum for the net-centric war-fighting environment. It will include operational planning, frequency assignments, spectrum supportability, regulation and policy, electromagnetic compatibility and modeling and simulation. It will hopefully be able to be a partner application to the spectrum management TTP discussed earlier.

IV. Conclusion

Summary

Chapter 2 provided an overview of frequency management principles, doctrine, organizations, training and materiel. It identified problem areas in the handling of national allotment plans, the lack of quality and speed on handling spectrum certifications, lack of a comprehensive spectrum doctrine, providing qualified instructors for spectrum management training, and the need for updating spectrum management software and databases.

Chapter 3 made recommendations in the spectrum management field which included: fixing the spectrum certification process; shortening the frequency assignment cycle; combining the JSIR and AFISR programs and providing software that would make it easier for users to submit; and publishing a TTP for spectrum management.

Good spectrum management is fundamental for being able to conduct military operations. Training, strategies, and up to date software is mandatory to meet these requirements.

Further Research

The following areas require further research to enhance spectrum management as it joins in the cyber warfare arena:

- A complete examination of the spectrum certification area using metrics from the military service FMOs and identifying ways to shorten the process.
- Software applications which would lead to improving the JSIR process.

- A complete look at what elements should be included in a TTP for spectrum management.

- Training areas that will improve the spectrum management field to take part in offensive and defensive cyber operations.

Appendix A

Terms and Definitions

Allocation: Entry in the Table of Frequency Allocations of a given frequency band for the purpose of its use by one or more (terrestrial or space) radiocommunication services or the radio astronomy service under specified conditions. (NTIA Manual, 2008)

Allotment: Entry of a designated frequency channel in an agreed plan, adopted by a component Conference, for use by one or more administrations for a (terrestrial or space) radiocommunication service in one or more identified countries or geographical areas and under specified conditions. (NTIA Manual, 2008)

Carrier Power: The average power supplied to the antenna transmission line by a transmitter during one radio frequency cycle taken under the condition of no modulation. (NTIA Manual, 2008)

Chip-Rate: The rate of encoding. (NTIA Manual, 2008)

Class of Emission: The set of characteristics of an emission, designated by standard symbols, e.g., type of modulation, modulating signal, type of information to be transmitted and also if appropriate, any additional signal characteristics. (NTIA Manual, 2008)

Direct Sequence Spread Spectrum: A signal structuring technique using a digital code sequence having a chip rate much higher than the information signal bit rate. Each information bit of a digital signal is transmitted as a pseudo-random sequence of chips. (NTIA Manual, 2008)

Duplex Operation: Operating method in which transmission is possible simultaneously in both directions of a telecommunications channel. (NTIA Manual, 2008)

Earth Station: A station located either on the Earth's surface or within the major portion of the Earth's atmosphere and intended for communications: (NTIA Manual, 2008)

a. with one or more space stations; or
b. with one or more station of the same kind by means of one or more reflecting satellites or other objects in space.

Effective Radiated Power (ERP): The product of the power supplied to the antenna and its gain relative to a half-wave dipole in a given direction. (NTIA Manual, 2008)

Electromagnetic Compatibility (EMC): The capability of electrical and electronic systems, equipment, and devices to operate in their intended electromagnetic environment within a defined margin of safety, and at design levels of performance without suffering or causing unacceptable degradation as a result of electromagnetic interference. (Joint Publication 1-02, 2001)

Electromagnetic Environmental Effects (E3): The impact of the electromagnetic environment upon the operational capability of military forces, equipment, systems, and platforms. It encompasses all electromagnetic disciplines, including electromagnetic compatibility and electromagnetic interference; electromagnetic vulnerability; electromagnetic pulse; electronic countermeasures, hazards of electromagnetic radiation to personnel, ordnance, and volatile materials; and natural phenomena effects of lightning and p-static. (Joint Publication 1-02, 2001)

Electromagnetic Interference (EMI): Any electrical or electromagnetic phenomenon—manmade or natural—causing an undesirable response, performance degradation, or complete malfunction of the equipment. Examples of causes of this phenomena are: Improper frequency management, improperly adjusted or malfunctioning electronic equipment, lightning, nuclear electromagnetic pulse, non-nuclear electromagnetic pulse, static electricity, motor ignition noise, microwave ovens, etc. (Joint Publication 1-02, 2001)

Emission: Radiation produced, or the production of radiation, by a radio transmitting station. For example, the energy radiated by the local oscillator of a radio receiver would not be an emission but a radiation. (NTIA Manual, 2008)

Frequency-Hopping Spread Spectrum: A signal structuring technique employing automatic switching of the transmitted frequency. Selection of the frequency to be transmitted is typically made in a pseudo-random manner from a set of frequencies covering a band wider than the information bandwidth. The intended receiver would frequency hop in synchronization with the code of the transmitter in order to retrieve the desired information. (NTIA Manual, 2008)

Frequency Tolerance: The maximum permissible departure by the center frequency of the frequency band occupied by an emission from the assigned frequency or, by the characteristic frequency of an emission from the reference frequency. The frequency tolerance is expressed in parts in 10^6 or in Hertz. (NTIA Manual, 2008)

Gain of an Antenna: The ratio, usually expressed in decibels, of power required at the input of a loss free reference antenna to the power supplied to the input of the given antenna to produce, in a given direction, the same field strength or the same power flux-density at the same distance. When not specified otherwise, the gain refers to the direction of maximum radiation. The gain may be considered

for a specified polarization. Depending on the choice of the reference antenna a distinction is made between:

a. absolute or isotropic gain (G_i), when the reference antenna is an isotropic antenna isolated in space
b. gain relative to a halfwave dipole (G_d), when the reference antenna is a half-wave dipole isolated in space whose equatorial plane contains the given direction
c. gain relative to a short vertical antenna (G_v), when the reference antenna is a linear conductor, much shorter than one quarter of the wavelength, normal to the surface of a perfectly conducting plane which contains the given direction (NTIA Manual, 2008)

Hertz: A unit of frequency which is equivalent to one cycle per second. (NTIA Manual, 2008)

Interference: The effect of unwanted energy due to one or a combination of emissions, radiation, or induction upon reception in a radiocommunication system, manifested by any performance degradation, misinterpretation, or loss of information which could be extracted in the absence of such unwanted energy. (NTIA Manual, 2008)

Mean Power: The average power supplied to the antenna transmission line by a transmitter during an interval of time sufficiently long compared with the lowest frequency encountered in the modulation taken under normal operating conditions. (NTIA Manual, 2008)

Necessary Bandwidth: For a given class of emission, the width of the frequency band which is just sufficient to ensure the transmission of information at the rate and with the quality required under specified conditions. (NTIA Manual, 2008)

Occupied Bandwidth: The width of a frequency band such that, below the lower and above the upper frequency limits, the mean powers emitted are each equal to a specified percentage B/2 of the total mean power of a given emission. Unless otherwise specified by the CCIR for the appropriate class of emission, the value of B/2 should be taken as 0.5%. (NTIA Manual, 2008)

Peak Envelope Power: The average power supplied to the antenna transmission line by a transmitter during one radio frequency cycle at the crest of the modulation envelope taken under normal operating conditions. (NTIA, 2008)

Radiocommunication: Telecommunication by means of radio waves. (NTIA Manual, 2008)

Radiodetermination: The determination of the position, velocity and/or other characteristics of an object, or the obtaining of information relating to these

parameters, by means of the propagation properties of radio waves. (NTIA Manual, 2008)

Radiolocation: Radiodetermination used for purposes other than those of radionavigation. (NTIA Manual, 2008)

Radionavigation: Radiodetermination used for the purposes of navigation, including obstruction warning. (NTIA Manual, 2008)

Radiosonde: An automatic radio transmitter in the meteorological aids service usually carried on an aircraft, free balloon, kite, or parachute, and which transmits meteorological data. (NTIA Manual, 2008)

Semi-Duplex Operation: A method which is simplex operation at one end of the circuit and duplex operation at the other. (NTIA, 2008)

Simplex Operation: Operating method in which transmission is made possible alternately in each direction of a telecommunication channel, for example, by means of manual control (NTIA Manual, 2008)

Spectral Power Density: The power density per unit bandwidth. (NTIA Manual, 2008)

Spread Spectrum: A signal structuring technique that employs direct sequence, frequency hopping or a hybrid of these, which can be used for multiple access and/or multiple functions. This technique decreases the potential interference to other receivers while achieving privacy and increasing the immunity of spread spectrum receivers to noise and interference. Spread spectrum generally makes use of a sequential noise-like signal structure to spread the normally narrowband information signal over a relatively wide band of frequencies. The receiver correlates the signals to retrieve the original information signal. (NTIA Manual, 2008)

Spurious Emission: Emission on a frequency or frequencies which are outside the necessary bandwidth and the level of which may be reduced without affecting the corresponding transmission of information. Spurious emissions include harmonic emissions, parasitic emissions, intermodulation products and frequency conversion products, but exclude out-of-band emissions. (NTIA Manual, 2008)

Telecommand: The use of telecommunication for the transmission of signals to initiate, modify or terminate functions or equipment at a distance. (NTIA Manual, 2008)

Telecommunication: Any transmission, emission or reception of signs, signals, writing, images and sound or intelligence of any nature by wire, radio, optical or other electromagnetic systems. (NTIA Manual, 2008)

Telegraphy: A form of telecommunication which is concerned in any process providing transmission and reception at a distance of documentary matter, such as written or printed matter or fixed images, or the reproduction at a distance of any kind of information in such a form. For the purposes of the Radio Regulations, unless otherwise specified therein, telegraphy shall mean a form of telecommunication for the transmission of written matter by the use of a signal code. (NTIA Manual, 2008)

Telemetry: The use of telecommunication for automatically indicating or recording measurements at a distance from the measuring instrument. (NTIA Manual, 2008)

Telephony: A form of telecommunications set up for the transmission of speech or, in some cases, other sounds. (NTIA Manual, 2008)

Television: A form of telecommunication for transmission of transient images of fixed or moving objects. (NTIA Manual, 2008)

Terrestrial Radiocommunication: Any radiocommunication other than space radiocommunication or radio astronomy. (NTIA Manual, 2008)

Terrestrial Station: A station effecting terrestrial radiocommunication. (NTIA Manual, 2008)

Appendix B

Table of Services, Station Classes and Stations

SERVICE	STATION CLASS	STATION
1. Amateur	None	Amateur
2. Broadcasting	BC	Broadcasting (sound)
	BT	Broadcasting (television)
3. Broadcasting-Satellite	EB	Space (sound)
	EV	Space (television)
4. Earth-Exploration-Satellite	EW	Space
	EWED	Space Telecommand Space Station
	EWEK	Space Tracking Space Station
	EWER	Space Telemetering Station
	TW	Earth
	TWTD	Space Telecommand Earth Station
	TWTK	Space Tracking Earth Station
	TWTR	Space Telemetering Earth Station
Meteorological-Satellite	EM	Space
	EMED	Space Telecommand Space Station
	EMEK	Space Tracking Space Station
	EMER	Space Telemetering Space Station
	TM	Earth
	TMTD	Space Telecommand Earth Station
	TMTK	Space Tracking Earth Station
	TMTR	Space Telemetering Earth Station
5. Fixed	FX	Fixed
	FXD	Telecommand Fixed
	FXE	Telemetering Fixed
	FXH	Hydrologic and Meteorological Fixed
Aeronautical Fixed	AX	Aeronautical Fixed
6. Fixed-Satellite	EC	Space
	ECED	Space Telecommand Space Station
	ECEK	Space Tracking Space Station
	ECER	Space Telemetering Space Station
	TC	Earth
	TCTD	Space Telecommand Earth Station
	TCTK	Space Tracking Earth Station
	TCTR	Space Telemetering Earth Station
	VA	Land Earth
7. Inter-Satellite	ES	Space
	ESED	Space Telecommand Space Station
	ESEK	Space Tracking Space Station
	ESER	Space Telemetering Space Station
8. Meteorological Aids	WXB	Radar Beacon Precipitation Gauge
	WXD	Meteorological Radar
	WXR	Radiosonde
	WXRG	Radiosonde Ground

SERVICE	STATION CLASS	STATION
9. Mobile	FL	Land
	FLD	Telecommand Land
	FLE	Telemetering Land
	FLEA	Aeronautical Telemetering Land
	FLEB	Flight Telemetering Land
	FLEC	Surface Telemetering Land
	FLH	Hydrologic and Meteorological Land
	FLU	Aeronautical Utility Land
	MO	Mobile
	MOB	Radio Beacon Mobile
	MOD	Telecommand Mobile
	MOE	Telemetering Mobile
	MOEA	Aeronautical Telemetering Mobile
	MOEB	Flight Telemetering Mobile
	MOEC	Surface Telemetering Mobile
	MOH	Hydrologic and Meteorological Mobile
	MOP	Portable Mobile
	MOU	Aeronautical Utility Mobile
Aeronautical	FA	Aeronautical
	FAB	Aeronautical Broadcast
	FAC	Airdrome Control
	FAD	Telecommand Aeronautical
	FAT	Flight Test
	MA	Aircraft
	MAD	Telecommand Aircraft
	MAP	Portable Aircraft
Aeronautical Mobile (OR)	FG	Aeronautical
Aeronautical Mobile (R)	FD	Aeronautical
Aeronautical Multicom	None	Aeronautical Multicom Land
	None	Aeronautical Multicom Mobile
Land Mobile	FB	Base
	FBD	Telecommand Base
	ML	Land Mobile
	MLD	Telecommand Land Mobile
	MLP	Portable Land Mobile
Maritime Mobile	FC	Coast
	FCB	Marine Broadcast
	FCD	Telecommand Coast
	MS	Ship
	MS	Telecommand Ship
	MSP	Portable Ship
	OD	Oceanographic Data
	OE	Oceanographic Data Interrogating
10. Mobile Satellite	UA	Mobile Earth
	TE	Satellite EPIRB
	TETD	Space Telecommand Transmitting Earth
	TETK	Station
	TETR	Space Tracking Transmitting Earth Station
	EI	Space Telemetering Transmitting Earth
	VA	Station
		Space
		Land Earth

SERVICE	STATION CLASS	STATION
Aeronautical Mobile-Satellite	EJ	Space
	EJED	Space Telecommand Space Station
	EJEK	Space Tracking Space Station
	EJER	Space Telemetering Station
	TB	Earth
	TBTD	Space Telecommand Earth Station
	TBTK	Space Tracking Earth Station
	TBTR	Space Telemetering Earth Station
	TJ	Aircraft Earth
	TJTD	Space Telecommand Earth Station
	TJTK	Space Tracking Earth Station
	TJTR	Space Telemetering Earth Station
Land Mobile-Satellite	EU	Space
	EUED	Space Telecommand Space Station
	EUEK	Space Tracking Space Station
	EUER	Space Telemetering Space Station
	TU	Land Mobile Earth
	TUTD	Space Telecommand Earth Station
	TUTK	Space Tracking Earth Station
	TUTR	Space Telemetering Earth Station
	TY	Base Earth
	TYTD	Space Telecommand Earth Station
	TYTK	Space Tracking Earth Station
	TYTR	Space Telemetering Earth Station
Maritime Mobile-Satellite	EG	Space
	EGED	Space Telecommand Space Station
	EGEK	Space Tracking Space Station
	EGER	Space Telemetering Space Station
	TG	Ship Earth
	TGTD	Space Telecommand Earth Station
	TGTK	Space Tracking Earth Station
	TGTR	Space Telemetering Earth Station
	TI	Coast Earth
	TITD	Space Telecommand Earth Station
	TITK	Space Tracking Earth Station
	TITR	Space Telemetering Earth Station
11. Radio Astronomy	RA	Radio Astronomy
12. Radiodetermination	None	Radiodetermination
	RG	Radio Direction-Finding
Radiolocation	LR	Land
	MR	Mobile
	MRP	Portable
Radionavigation	NR	Mobile
	RLN	Loran
	RN	Land

SERVICE	STATION CLASS	STATION
Aeronautical Radionavigation	RLA	Marker Beacon
	RLB	Radiobeacon
	RLC	Radarbeacon (Racon)
	RLG	Glide Path (Slope)
	RLL	Localizer
	RLO	Omnidirectional Range
	RLR	Radio Range
	RLS	Surveillance Radar
	RLTM	Land Test (Maintenance)
	RLTO	Land Test (Operational)
	ROA	Altimeter
Maritime Radionavigation	RLC	Radar Beacon (Racon)
	RLM	Marine Radiobeacon
13. Radiodetermination-Satellite	EF	Space
	EFED	Space Telecommand Space Station
	EFEK	Space Tracking Space Station
	EFER	Space Telemetering Station
	TF	Earth
	TFTD	Space Telecommand Earth Station
	TFTK	Space Tracking Earth Station
	TFTR	Space Telemetering Earth Station
	TK	Mobile Earth
	TKTD	Space Telecommand Earth Station
	TLTK	Space Tracking Earth Station
	TLTR	Space Telemetering Earth Station
Radionavigation-Satellite	EN	Space
	ENED	Space Telecommand Space Station
	ENEK	Space Tracking Space Station
	ENER	Space Telemetering Station
	TN	Fixed Earth
	TNTD	Space Telecommand Earth Station
	TNTK	Space Tracking Earth Station
	TNTR	Space Telemetering Earth Station
	UM	Mobile Earth
Aeronautical Radionavigation-Satellite	EO	Space
	EOED	Space Telecommand Space Station
	EOEK	Space Tracking Space Station
	EOER	Space Telemetering Station
	TO	Mobile Earth
	TOTD	Space Telecommand Earth Station
	TOTK	Space Tracking Earth Station
	TOTR	Space Telemetering Earth Station
	TZ	Aircraft Earth
	TZTD	Space Telecommand Earth Station
	TZTK	Space Tracking Earth Station
	TZTR	Space Telemetering Earth Station

SERVICE	STATION CLASS	STATION
Maritime Radionavigation-Satellite	EQ	Space
	EQED	Space Telecommand Space Station
	EQEK	Space Tracking Space Station
	EQER	Space Telemetering Space Station
	TQ	Ship Earth
	TQTD	Space Telecommand Earth Station
	TQTK	Space Tracking Earth Station
	TQTR	Space Telemetering Earth Station
	TX	Coast Earth
	TXTD	Space Telecommand Earth Station
	TXTK	Space Tracking Earth Station
	TXTR	Space Telemetering Earth Station
14. Space Operation	ET	Space
	ETED	Space Telecommand Space Station
	ETEK	Space Tracking Space Station
	ETER	Space Telemetering Station
	TT	Earth
	TTTD	Space Telecommand Earth Station
	TTTK	Space Tracking Earth Station
	TTTR	Space Telemetering Earth Station
15. Space Research	EH	Space
	EHED	Space Telecommand Space Station
	EHEK	Space Tracking Space Station
	EHER	Space Telemetering Station
	TH	Earth
	THTD	Space Telecommand Earth Station
	THTK	Space Tracking Earth Station
	THTR	Space Telemetering Earth Station
16. Standard Frequency and Time Signal	SS	Standard Frequency and Time Signal
17. Standard Frequency and Time Signal-Satellite	EE	Space
18. No specific Service	ED	Space Telecommand Space
	EK	Space Tracking Space
	ER	Space Telemetering Space
	EX	Experimental Station
	ME	Space Station
	SN	Sounder Network
	SP	Sounder Prediction
	TD	Space Telecommand Earth
	TK	Space Tracking Earth
	TR	Space Telemetering Earth
	XC	Experimental Contract Developmental
	XD	Experimental Developmental
	XE	Experimental Export
	XM	Experimental Composite
	XR	Experimental Research
	XT	Experimental Testing

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14. ABSTRACT

Department of Defense spectrum management is a crucial element of our national defense. Within spectrum management we will either exercise proper controls or we will hamper our own ability to achieve victory. The spectrum management process does not belong to the Department of Defense (DoD), and we must work with other government agencies. Time tables are often short, especially during wartime operations, and this is all the more reason why spectrum management processes should be followed. This research includes an analysis of current National, DoD, Joint, and Air Force publications and instructions, as well as a review of Government Audit Agency studies to see where DoD is today regarding spectrum management. Recommendations are provided for improving visibility into spectrum management and to improve the overall process.

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